DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

PROBLEMS OF PROGRESS IN INDUSTRY—8

ERGONOMICS
OF
AUTOMATION

By A. T. WELFORD

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PREFACE

The object of this series is to present briefly and simply the results of new research into the economic, technical and human problems of industrial progress—problems arising from automation and other advances in techniques, and problems of management and social relations.

The series is commissioned and edited by the Department of Scientific and Industrial Research, which seeks to provide a forum for responsible new thinking and to stimulate independent discussion and action, including further research. The conclusions and speculations are those of the investigators, mostly from the universities and other well-known research bodies.

The Department recently sponsored a study of the human implications of automation. This was carried out under the direction of Mr. A. T. Welford, and included a survey by Dr. E. R. F. W. Crossman of existing practice in industry and a critical appraisal by Miss H. M. Clay and Mr. Welford of recent research. The present issue discusses research relevant to the problems of the human operator in an automatic plant, with special emphasis on the design of equipment. An account of the industrial survey, by Dr. Crossman, will be published shortly as No. 9 in this series, under the title 'Automation and Skill'. The two booklets together constitute the final report of this study.

Information Division,
Department of Scientific and Industrial Research,
14–18 Cornwall Terrace, London, N.W.1. *June* 1960

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Pen drawings by Margaret Wetherbee

I. THE ERGONOMIC APPROACH TO AUTOMATION

It is generally recognized that the spread of automatic methods in industry and offices has important implications not only for productivity and organization but also for the demands made by work on individual men and women. Some of the changes in demands result directly from the altered role of the machine operator, others are social in nature due to the fact that often fewer people are employed in any one plant, others again are many-sided in that the economic requirement to use expensive equipment both day and night implies an increased amount of shift work in some factories and its introduction into offices.

Adequate work performance depends upon the capacities of the workpeople being able to meet the demands of the job and its equipment, and to sustain any stresses there may be from the environment in which work is carried out. To assess the human effects of automation, human capacities and job characteristics have therefore to be considered together in a comparison of the new jobs with those they replace.

The knowledge required is penetrating and varied. Is the physical effort the job demands within the operator's capabilities? Are the various controls he has to use in positions in which he can apply the necessary force to them without strain? Is the posture he must adopt comfortable? Perhaps it is even more important to know whether the 'mental load' is within his capacities, whether information is displayed clearly, whether the job is 'complicated' or 'confusing' and whether it involves stresses such as the anxiety and emotional strain that come from chronic danger. Furthermore, account must be taken not only of the job itself but also of the environment in which it is done. For example, work done easily at normal room temperature may become much more difficult under conditions of high temperature and humidity. Again, a job which is attractive when carried out in close contact with a group of congenial workmates, may become distasteful if it has to be done under conditions of isolation.

One of the most significant developments during the second world war was the attempt to get away from trying to match men to machines by selection and training, and to design equipment in such a way that its operation was within the capacities of most normal people. This 'fitting the job to the man' meant a collaboration of engineers with those trained in the fundamental human scientific disciplines of anatomy, physiology and experimental psychology. The value of this collaboration was strikingly illustrated in the development of certain types of military equipment. The wartime work was, however, an expansion of an approach which had begun before the war in industry, and during the post-war years attention has returned to the industrial field. Here the approach has increasingly shown its value as an ally, according to circumstances, of design engineering, work-study, industrial medicine and personnel management. The contribution of experimental psychology has come to be known as *human engineering* or *engineering psychology*. More recently the term *ergonomics* has come into use to cover both this and also the contributions of anatomy and physiology.

The purpose of this pamphlet is to survey in broad outline those aspects of ergonomics which are likely to bear on questions of designing automatic equipment, and on the human problems likely to arise in 'automation' work. It does not attempt to give specific directions on particular problems, but is designed to indicate the scope of existing knowledge and to guide the reader to sources of further information. Some of the relevant points have been well known for many years; others are only just beginning to be recognized.

The immediate human question that automation raises for most people is the extent to which traditional skills will become redundant and new ones be required. Behind this question lie three more basic problems; firstly, the definition of industrial skills; secondly, the design of machines in such a way that they are easy to use quickly and accurately; and thirdly, certain fundamental human abilities and limitations both physical and mental. Ancillary problems almost inevitably arise from the increase of shift work, changes in the structure of working groups, effects on satisfaction with work and the need for retraining for the new job.

The scope of automation

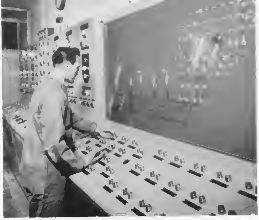
The developments now known as automation have grown out of the piecemeal mechanization that has been gradually producing a 'new industrial revolution' over many years. In the present context three main types may be distinguished.

1. *The replacement of manufacturing methods in which each product is dealt with separately, or in a batch, by some form of continuous-flow process.* The most clear-cut examples of these processes are in the chemical and petroleum industries. The same principles are, however, widespread and apply, for example, to transfer machining in engineering works, where a product is automatically passed from one stage in manufacture to another.

If carried to their logical limits these developments would result in completely automatic factories where all stages of manufacture could be accomplished with no human intervention. Such a state of affairs has not yet been realized. The processes commonly included under the heading of 'automation' are carried out by machinery which although automatic in operation still leaves the human controller a substantial part to play. In many cases the process has to be controlled by the direct action of an operator. In others, automatic devices exercise routine control, but leave the operator the tasks of monitoring the process and of over-riding the automatic controls in case of emergency. These processes thus link closely with certain other remote-control operations such as railway signalling and the control of planes at airports.

2. *The automatic machining of engineering products by means of electronically controlled machine tools.* The tool is controlled, via an electronic control unit, by a magnetic tape or a punched tape or card. The operator has to monitor the machine but no longer has the task of accurately determining the individual machining operations. Whereas the first type of automation applies only to large-scale manufacture, this second type can apply throughout the range right down to 'one-off' jobs.

3. *The use of high-speed computers in offices.* These enable various routine accounting operations, such as those for payrolls, to be done with less labour and greater accuracy. They also, by virtue of the large amount of detailed calculation they



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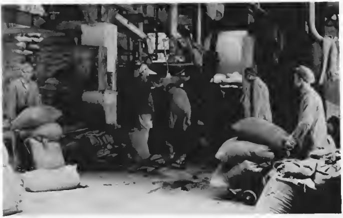
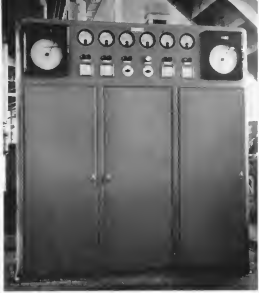
Old and New Methods of Processing Animal Feeding Stuffs

With the new method, weighing, mixing and grinding are carried out by a series of machines, most of which are automatic and controlled from the panel shown above. The new method involves none of the heavy manual work that characterized the old method illustrated below and also saves manpower, since the seven men formerly required are replaced by one operator at the control panel. The operator is, however, subject to a mental load which the old method did not impose. This load arises because the operator is no longer in contact with the material and cannot see what is happening to it. He deals with it indirectly by means of push buttons which start and stop the several machines. Some help in visualizing the process is provided by the mimic display. The help might have been greater if the push buttons had been mounted at the appropriate points on the display.





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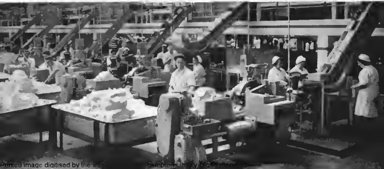
Old and New Methods of Manufacturing Margarine

The old method illustrated below involved several stages between which the part-finished product had to be conveyed by truck and shovelled into hoppers. In the new method the stages of manufacture are linked together into a continuous process. The heavy manual labour of shovelling by the man in the photograph below is no longer required. Instead the operator has to set and occasionally adjust controls in the light of indications on the display panel shown in the photograph above. Whereas, with the old method, the product could be inspected at all stages of manufacture, with the new method the operator has no easy means of inspecting the product until after the final packaging has taken place.



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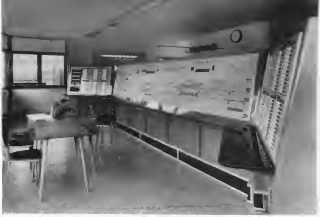

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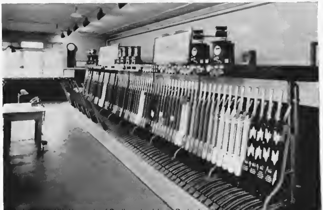
The new signal box shown above has many important advantages over the older box shown below. Three of these are:

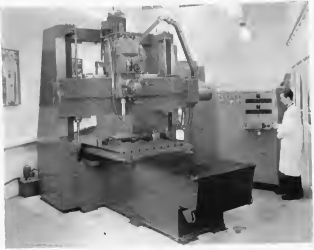
(a) The physical effort of moving heavy levers is no longer required. Instead, the signalman presses small buttons on the track diagram at the beginning and end of the route he wishes to set up. Operating two buttons in this way sets all signals and points over a given stretch of line.

(b) The placing of the control buttons on the diagram avoids the difficulty inherent in the old-type box of relating the illuminated track diagram to the levers and signal indications.

(c) In the old-type box, trains coming from the areas controlled by adjacent boxes are described by a system of bell codes and information from these has to be remembered by the signalman. In the new box, descriptions of trains coming from adjacent areas are indicated by lights on the panels at either end of the track diagram. The lights remain illuminated until the trains have passed and thus they relieve the load upon the signalman's memory.

It should be noted that the length of track which can be controlled by one signalman is very much greater with the new type of box than with the old.





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A Tape-Controlled Drilling Machine

The positioning of the work and sequence of operations is determined by a punched paper tape used with the electronic control unit on the right. The work of a traditionally skilled tradesman in operating the machine is therefore eliminated. Traditional skill is, however, still required for tool-setting and for checking the accuracy of the work done.

achieve in a short time, can provide management with a wider range of technical and business information and so enable it to exercise much closer control over stocks, production programmes, and the disposition of transport facilities and other resources.

From the human point of view, work with all these types of automatic equipment falls into three classes:

- *a.* Setting out the processes: the order of operations in a continuous-flow process must be determined; the sequence of actions by a tape-fed machine tool must be worked out and punched on the control tape; the computers used in office work need 'programming'.
- *b.* Operating the processes and machines, and monitoring their working.

Reproduced by permission of LEO Computers Ltd.

This computer handles work which would otherwise require a large number of clerks, and experience has shown that it does its work many times faster and more accurately. The data is fed in by means of punched cards and tapes. The device which reads the tapes can be seen in the centre foreground. To keep the computer continually fed with information, a substantial number of girls are engaged on punching tapes. The girls require the skill of a copy-typist rather than that of a clerk. Results of the calculations done by the computer are punched into filing cards and also printed on paper rolls. The printers can be seen on either side of the control desk.

c. Keeping the equipment in running order and repair.

The first of these three classes of work has, unfortunately, not yet been systematically studied to any appreciable extent. The main emphasis in this booklet will therefore be on operators and maintenance engineers, and among these, present knowledge makes it inevitable that the main stress should be on those dealing with large-scale continuous-flow equipment rather than with electronically-controlled machine tools or high-speed computers.

Traditional industrial skills

The customary industrial definition of 'skilled work' is that for which an apprenticeship training is required, as opposed to 'unskilled work' which needs no training beyond that which common experience of life can provide. Semi-skilled work is regarded as falling between these two in that it requires a period of training or experience on the job shorter than a full apprenticeship. It has indeed been suggested that the period of training or experience needed can give an indication of the 'level' of any semi-skilled job.

Few people are entirely satisfied with this type of definition. It is often argued that the grading of a job is more a matter of its history or of the bargaining power of a craft union than of current job requirements. The fundamental objection to such a definition is, however, that skill results from knowledge and *expertise* which are gained by *experience*, rather than from mere exposure to training. If this fact is accepted, it must be obvious that many jobs are highly skilled even though they are not approached through a formal apprenticeship. In order to assess skill in this more fundamental sense, it is necessary to consider not only length of training, but also the various ways in which performance can display an expert quality.

Broadly speaking a man who is skilled, either in the traditional or in the wider sense, possesses two important abilities:

1. He has a knowledge of the products of his craft, or of the objects of his trade, and of the materials he handles, so that his work is not carried out by 'rule of thumb' but with insight into what is being done and why. This insight lends flexibility to his approach and means that he can do a wider variety of jobs than one who is not skilled.
2. He has at his command a range of procedures or 'strategies' which give his performance a similar flexibility under changing conditions of work, and enable him to order and co-ordinate his efforts in a wider range of conditions than a man who is not skilled.

He has also one or more of three further abilities:

3. Fine, detailed control of action in using tools, especially hand tools, for both the graded application of force and the rhythm and timing of actions.

4. Fine judgement of sensory qualities such as colour, sound or texture. The quality judged varies from one job to another and the ability acquired is usually specific to the job concerned.
5. The ability to imagine and understand 'in the abstract' processes and events that are not directly observable. This is especially required in the case of electricians.

Changes of demand for skill among operatives

The most obvious change in demand upon operatives resulting from automation is the shift from manual to a more 'intellectual' type of skill; as a speaker once felicitously put it 'the machine operator is becoming a *mental craftsman*'. The change makes work both easier and more difficult. Replacement of hand-tools which require less finely graded hand movements, can bring substantial easing of work as these movements are often some of the most difficult features of traditional skills, requiring constant practice if a high level of performance is to be maintained—the rustiness of a tennis player at the beginning of a season, or of a concert pianist out of practice, has its industrial counterparts.

At the same time, however, replacement of hand tools by machines may substantially increase the *mental load* upon the operator because it complicates the relationship between what he sees and the actions he takes. With hand tools, this relationship is simple and direct, depending upon 'rules' of co-ordination between eye and hand learnt early in life. With machine tools, however, there is an element of 'arbitrariness' in the sense that the actions of levers, handwheels and other controls bear only indirect or symbolic relationships to their effects.

All these tendencies are carried further in remote-control systems than they are in more conventional mechanization. With remote control there is usually less effort involved in moving around to keep check on machinery and still less requirement of finely graded muscular action, but the operator is no longer able to observe the process directly, having instead to rely on the symbolic indications of meters or other signalling devices.

The difficulty resulting from increase of mental load upon the operative can, unless care is taken, far outweigh any easing of the task in terms of physical effort or fine muscular control. Whether or not it does so depends upon a number of detailed points in the design of the machinery concerned and the extent to which automation is carried. For example, *remote* control of operations without *automatic* control is liable to make the operator's mental load so great that his job is far more difficult than almost any in a conventional factory. Where, however, fully automatic control is installed, the operator's mental load is likely to be very substantially lightened.

Although automation may lessen the need for traditional skill, the need remains for some expertise or skill in the wider sense. This is shown by the effects that come from the knowledge possessed by a man who has controlled the same plant for a long time. His understanding is often incomplete and may not be wholly accurate, and his performance may not have acquired flexibility beyond that needed for the particular machines he uses. He is, nevertheless, skilled in the sense that he possesses a 'mental picture' of his machine and its working, which enables him to get more from it and to be 'kinder' to it than a less experienced man. This type of skill has been aptly termed 'control skill'.[1]

In one sense it can, of course, be said that automation does not in any of its forms dispense with the need for skills of the traditional types, but merely shifts the need for them back from operatives to those who construct and maintain the automation plant. While this is undoubtedly true, there is a clear gain from automation in that human skill is no longer used repetitively for the manufacture of each individual article, but is reserved for those operations of control and construction in which the adaptability of human beings can be used to full advantage. Viewed in these terms automation appears not as an abolisher but as a conserver of skill.

Skill required of maintenance staff

Much of the maintenance work on automatic machinery is that for which a trained fitter is required. Whether the full training of an apprenticeship is needed or whether some shorter course of instruction will suffice depends partly upon the factory organization and partly upon the construction of the machinery concerned. For example, rigid standardization of replacement parts simplifies maintenance and reduces, although it does not entirely remove, the need for fully trained fitters.

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[1] Crossman, E. R. F. W. Automation and Skill. *Problems of Progress in Industry*, No. 9.

The maintenance of electronic equipment presents an additional problem since the fully competent electrical or electronic tradesman requires an intellectual capacity attained by relatively few people. The type of ability required appears to be similar to that needed for performing so-called 'intelligence' tests, and it is noteworthy that studies of Naval personnel during the war found that electrical artificers attained intelligence test scores higher on average than those of any other class of rating.[1] They were a little higher than those of R.N. executive officers and Fleet Air Arm observers and pilots, and were exceeded only by those of R.N. engineer officers. It seems clear that any large scale expansion of the need for electronic maintenance tradesmen with the qualifications now customary would cause a serious drain on intellectual manpower. This fact seems to have been tacitly recognized in the attempts now being made to simplify electronic maintenance so that it can be carried out by less gifted people.

Personal qualities

In many operations certain personal qualities broadly indicated by the terms 'stability' and 'sense of responsibility' need to be taken into account when assessing the grade and status of employees. These are just as important as skill, although probably not subject to much improvement with training. In many of the more advanced forms of mechanization and process control the operator can be thought of as exercising the function of a supervisor and as requiring the attitudes and personal qualities appropriate to that grade, although his supervision is of machines rather than of men.

These personal qualities and the stability of employment needed if 'specific control skill' is to be developed, mean that the status of operators is likely to rise as automatic equipment becomes established.

[1] VERNON, P. E. *American Psychologist* 1947, **2**, pp. 35–51.

The net effect of these changes

It is a well-nigh impossible task to forecast any overall effect of automation on employment and redundancy over the next few years, but the indications are that it is likely to be much less than is sometimes believed and feared. Automatic methods are applicable only to a limited range of manufacturing and office procedures. All work involving personal attention must remain largely unaffected, and even in highly mechanized factories human operatives are likely to continue for a long time to be the most economic means of carrying out many assembly and inspection operations. Indeed, the need for men and women to inspect products may substantially rise since automatic processes often cut down the amount of inspection that can be done by an operator in the course of actual production.

Furthermore, even where new machinery effects a substantial saving of operators for a given output, the increase of maintenance and servicing work can often absorb many who would otherwise be redundant, and the tendency for output to rise and the fact that the automatic methods open up possibilities of manufacture not present with older methods, are likely to increase available jobs still more. There seems no justification, therefore, for the fear that the introduction of automatic methods will cause widespread unemployment. Indeed the reverse seems more likely.

Suggestions for further reading

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. *Automation*. London: H.M.S.O. 1956.

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HUGHES, E. M. (ed.). *Automation in Theory and Practice*. Oxford: Blackwell. 1956.

INSTITUTION OF PRODUCTION ENGINEERS—*The Automatic Factory: What does it mean?* London: E. & F. N. Spon Ltd. 1955.

MACMILLAN, R. H. *Automation—Friend or Foe?* Cambridge University Press. 1956.

SOUTHWELL, E. *Application of Automation in Europe*. Trade Union Information and Research Service. European Productivity Agency, Paris.

II. DESIGN FOR EASE OF OPERATION

When assessing the demands of work involving heavy physical effort it is appropriate to think of man as a heat engine converting calories from food into muscle power. Mechanization, however, makes this analogy of little importance and stresses instead the fact that man is a *communication channel* taking in information through his senses and using it as a basis for guiding action.

The actual sense organs and the members with which action is taken are seldom the links in this chain which set limits to his performance: the limitations lie rather in the brain 'mechanisms' involved in perception, in relating perception to action and in the shaping and ordering of movements. It is, therefore, convenient to consider firstly the *presentation of information* to the operator; secondly the *design of machine controls*; and thirdly the effects upon ease of operation of different relationships between the information presented and the responding action required, or as they are termed *relationships between display and control.*

1. PRESENTATION OF INFORMATION

One of the most thoroughly worked areas in this field is the optimum design of scales. Some of the recommendations from this work are obvious, others less so. The main ones are:

(i) The length of the scale and thus, ultimately, the size of the instrument, must be related to the distance at which the scale is to be viewed.

(ii) Some scale shapes are easier to read than others; for example, circular dials have been found easier than linear scales, and among the latter horizontal have been found easier than vertical.

(iii) If speed of reading is not a consideration, scales are read more accurately when individual scale marks are placed for each unit. Quick check readings, however, are made more accurately if fewer marks are provided and the reader interpolates between them. Interpolation can usually be made accurately into five parts. Thus when a scale is to be read to an accuracy of 1 per cent, only 20 scale marks should be provided.

(iv) The numbering should be in ones, twos, fives, or in multiples or sub-multiples of these by 10 or 100, rather than in threes, fours or other intervals.

(v) The scale division marks should not be enclosed between parallel lines.

(vi) The area swept by the pointer of an instrument should be clear of marks, such as the maker's name, or the statement of what the instrument shows, such as 'current consumption' or 'air pressure', or the designation of units, such as 'milliamps' or 'lb. per sq. in.'

(vii) The pointer should reach the scale division marks and, while it should be thick enough to be seen against the instrument face, it should be thin enough where it reaches the scale to enable a precise reading to be made.

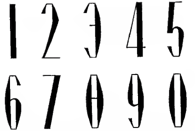
(viii) The pointer should normally move clockwise on a circular dial or to the right or up on a linear scale to indicate increase.

(ix) Figures should be oriented in such a way that they are read upright and, other considerations being equal, positioned so that they are not covered by the pointer. The main exception to this occurs with circular scales where placing of the figures inside the scale marks and allowing the pointer to move over them enables a larger scale to be provided for a given diameter of instrument face.

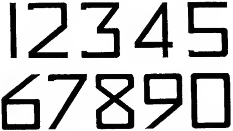
(x) Too low an angle of viewing may cause errors of reading.

(xi) Moving scales may, in certain circumstances, be more accurately read than moving pointers, although they are slower to use for check readings. When extreme accuracy is required, counters are recommended instead of scales.

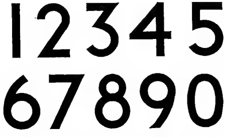
Optimum values have also been ascertained for the sizes of numbers and letters, for the relation of height to width, for the



A set of figures in current use on a car speedometer. Designed to be of striking and decorative appearance, they have poor legibility. Note, for example, the possibility of confusion between 8 and o, and between 6 and 5.

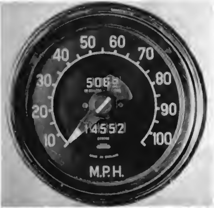


These figures were designed to be clearly legible and easily distinguishable from each other. They have the disadvantage that they look somewhat unattractive.

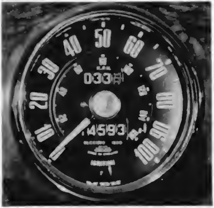


Legibility and easy discrimination are combined with good appearance on these figures. They have been constructed taking both form and width of stroke into account.

(a)



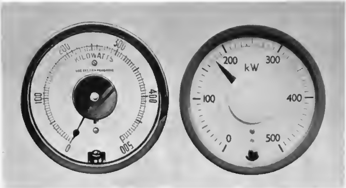
(b)



Good and Poor Designs of Speedometers

The figures on example (*a*) are very much easier to read than those of example (*b*). Not only are they of better form but all are oriented so that they are read the right way up. Although the scale length of the upper example is less than that of the lower, the accuracy with which the speedometer is read is sufficient for this to be unimportant.

Almost all speedometers have the disadvantage that the mileometer counters are partially obscured by the pointer at certain speeds. Example (*a*) attempts ingeniously to overcome this by making part of the pointer transparent. This, however, makes the pointer less clearly visible than it would be if it was white along the whole of its length. The fundamental solution would be to remove the mileometer counters from the part of the dial face swept by the pointer.



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Old and New Versions of a Meter Dial

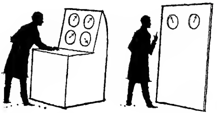
The scale of the old version is difficult to read quickly. Not only are there too many marks, but the enclosure of these between parallel lines is confusing. The scale of the new version is much more easily read. The figures of the old version have the advantage that they are not at any time covered by the pointer, but the increased scale length of the new version and the fact that the new figures are all upright more than outweighs this. Both versions transgress good design in placing the legend 'Kilowatts' or 'kW' on the portion of the dial face swept by the pointer.

The heavy, polished black centre and bezel distract attention from the scale and pointer in the old version. The matt grey bezel and white centre of the new version are improvements. The new version would have been better still if the large centre piece had been eliminated and the pointer continued to the centre of the dial face. The new version has the refinement that the scale itself is raised a little above the rest of the dial face, an arrangement which avoids difficulties due to parallax between the pointer and the scale if the meter has to be read at an angle.

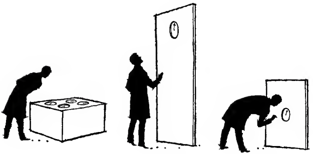
relation of stroke width to size, and for the spacing between individual digits and letters.

Few meters and other devices incorporating scales which are in use today conform to these recommendations. Several manufacturers are, however, altering their designs in the light of recommendations such as these. Others are as yet unwilling to adopt designs which they believe may not be acceptable to customers. Responsibility for changing designs should not be placed upon manufacturers alone but must also rest upon users.

Scales are, of course, only one way of displaying information and any comprehensive survey should also cover other signalling devices both visual and auditory. Less systematic work has been done on these but taking the results together with what is known generally about perception, a number of points seem clear enough.



Good Good



Bad Too high Too low

Positioning of Instrument Dials

Instruments should be positioned so that their faces are perpendicular to the line of sight and at or a little below eye level.

Adequacy of signal

Signals must obviously be of a sufficient strength and size to be received clearly by the sense organs concerned. Such tasks as the discrimination of fine detail are profoundly affected by lighting, glare, vibration and the contrast of figures or other indicators with their background. Poor conditions in any of these may not lead to a total breakdown of performance but they are likely to make it slow and thus cause trouble in times of stress or emergency.

It goes without saying that signals requiring different actions should be clearly distinguishable from one another, but the implications of this are not quite as obvious as they might seem. Sensitivity is normally greater *to differences between stimuli* than to their absolute magnitudes. Thus while most people are extremely sensitive to change in the pitch of a note, few have the ability to recognize 'absolute pitch'. In the same way, it is easier to perceive a change of intensity in a light or sound than it is to judge brightness or loudness in the absence of change. When, for example, brake lights of a car are combined with rear lights it is not easy to decide whether they are on unless the actual moment of braking is observed. The difficulty would be removed if the brake lights flashed continuously while the brake was acting or if they were in a different position, and perhaps of a different colour, from the rear lights. The number of intensities or pitches that can be *confidently* distinguished in an absolute way is probably very small and it seems best to avoid signals which depend on this type of discrimination.

Colours are more easily discriminated than intensities. The number of spectral hues absolutely identifiable by a person with normal colour-vision is put at between six and eleven by different authors, ease of identification depending somewhat on how far the colours can be given names.

Colours may, however, be less reliably distinguished than signals showing numbers, letters or other symbols. The main reason is, presumably, that the operator has to remember what the colours mean, but the numbers, letters or other symbols, can be chosen to convey their meaning directly. Colour is perhaps most useful for enabling several light signals to be grouped together and separated from other groups.

Codes and meaning

The fact that an operator has to learn and remember what signals mean has other important implications beyond the one just noted. He may not be conscious of having to remember the meaning, but even when he is thoroughly experienced occasional lapses of memory may occur and lead to momentary confusion. Some codes, such as the association of red with danger, are so well known that they seem 'natural', although they are really arbitrary and have had to be learnt. A few researches have shown that some codes are easier to follow than others and that 'appropriateness' of symbols to the meaning they have to convey is a field needing further study. Although there is room for more research in this field, three points can be made from what is already known.

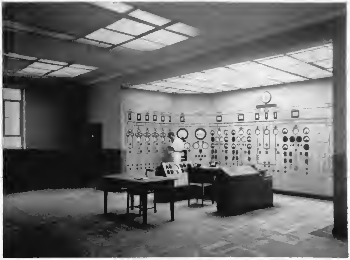
(i) Signal sources, such as instruments, should be clearly labelled with their functions.

(ii) Pictorial or semi-pictorial representation may in some cases be worth while even if more difficult to arrange, from an engineering point of view, than a simple but arbitrary code of signals such as coloured lights or pointer readings on dials.

(iii) Any one *set* of signals should, if possible, be logically connected according to a single principle so that only one 'rule' has to be learnt in order to understand the whole set.

Complexity and selection

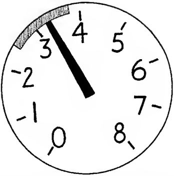
All perception is selective; some objects are observed while others are neglected. A large part of this selection is determined by the interests of the observer and the task he has on hand. However, some portions of a display tend to secure more attention than others, and certain stimuli such as bright lights, strong colours or loud, high-pitched sounds tend to attract attention away from the task in hand and thus to impair performance. There is considerable scope for designing visual displays so as to 'lead the eye naturally' to the points at which the required information is to be obtained and to avoid striking but irrelevant and, therefore, confusing, objects in the field of vision. For example, a heavy instrument bezel in polished black or chromium may distract attention from the pointer, or a maker's name plate in a prominent position may constitute a distraction on a display panel. Confusing conditions cannot always be avoided in a display and may not be noticed during



Note how the attention is drawn to the well-lit part of the room. The display shows up clearly under the high illumination provided, but it is possible that the very bright ceiling light would distract the operator's attention upwards. Note the diagrams on the panels indicating the functional relationships between certain of the instruments and controls.

normal working by an operator who is familiar with the machinery or plant concerned. However, the selectivity he is called upon to exercise imposes a load upon his perceptual powers, and the greater the load the more likely he is to make errors, especially in times of stress.

Confusing conditions of this kind are likely to occur where large amounts of data have to be presented together in a display comprising many instruments, for instance the large banks of dials in aircraft and many process control rooms. There are, however, ways in which the danger of confusion can be reduced. One example is the marking of permitted ranges of variation on the dials of instruments, so that the operator can identify deviations beyond these ranges without having to carry in mind the extent of the permitted zone. Another, which applies especially to large banks of indicators, is the alignment of scales so that the pointers, when reading correctly, are all in approximately the



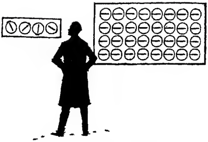
Marking the permissible range of variation on the instrument dial relieves the operator of the need to remember it and thus reduces the mental load and of the possibility of error.

same direction, and thus deviant readings stand out from the general pattern.

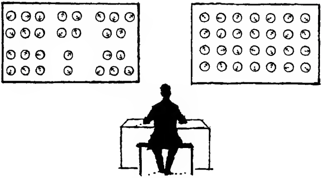
The spacing of different indicators can also be important. The rapid scanning of multi-indicator displays is obviously easier when the individual items are close together than if they are widely separated. It is, however, often difficult to pick out an individual item from a large block and where this has to be done it is desirable to divide the block into groups. The best arrangement is to place together indicators which are functionally related and separate them by a short distance from others. Groups of more than about seven items may be further sub-divided on an arbitrary basis.

Series of signals arriving at intervals over a period of time

Ideally, signals and responding actions should keep in step with one another. This requirement has two facets. Firstly, the signals for a series of actions will often best be given one at a time so that those for one action are not liable to be confused with those for another. Secondly, signals should, for maximum accuracy and ease of reading, give their information 'all at once' and not require the piecing together of data over a period of time.



It takes the operator the same time to check the four dials on the left as it does to check the 32 dials on the right. The difference is due to the fact that the scales of the right-hand bank are aligned so that when reading correctly the pointers are all in the same direction.



The slight spacing between groups makes it easier to identify a particular dial in the bank on the left than in that on the right.

Any requirement for integration of data means that information must be temporarily 'stored' in some form of short-term memory. 'Storage' of this kind appears to be of limited capacity and gives rise to a number of difficulties due to information being lost. This problem will be discussed in more detail later.

Visual versus sound indicators

Most indicators are either visual or auditory and there are certain fairly obvious differences between the types of data they convey best. Auditory signals have the advantage of being able to attract attention from any direction, but are ill-adapted to conveying precise information unless by speech. Much more information can be rapidly conveyed by vision, but only, of course, if the subject is looking in the appropriate direction. A combined auditory and visual system, often suitable where large displays have to be monitored, is an auditory warning of the imminent need for action combined with a simple visual signal, such as a light, indicating which part of the display is involved. The operator can then rapidly identify the instrument giving the detailed information which requires his attention.

The need for appropriate information

If equipment is to be well designed for use, it is necessary to consider what information the operator needs in order to do his work both accurately and with confidence. Broadly speaking, he must have data of two types. Firstly, he needs unambiguous indications of what is happening in the process he is controlling or monitoring, and of the effects of his actions upon it, and secondly, he should have *positive* indications that his apparatus is working properly and that the process is proceeding correctly. It is not enough for correct working to be signified by absence of any warning signal, because the operator may be seriously misled if the warning signal should fail and, even if it does not, the possibility of its doing so may destroy his confidence and thus impair his efficiency.

The information an operator requires in order to get the best out of his machine is often more than the designer has considered necessary, and operators tend to supplement the information given on the display panel by making use of 'unplanned' indications such as the sound of the machine running. The information an operator uses may be more than is logically necessary, but is probably required because the strictly logical approach would be beyond his intellectual powers. With this extra information operators can often obtain a performance from their machines beyond that envisaged by the designer even though they may have a very imperfect idea of how the machines work.

2. DESIGN OF MACHINE CONTROLS

Factors in the design of controls fall into two main groups. Firstly, there are anatomical considerations of body size, ranges of movement and the application of muscular force. Secondly, are several problems which have essentially to do with the perception required to grade movements accurately and to operate the correct controls in the right sequence when performing complex tasks.

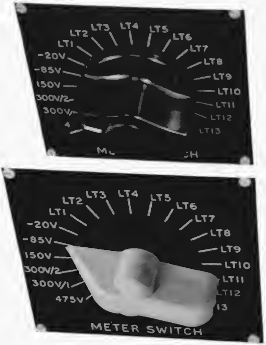
Anatomical considerations

Body measurements such as sitting height and length of limbs are important data for the design of vehicles and of many machine tools. Neglect of such data may make a machine well nigh impossible to use, or at least so uncomfortable that the operator cannot concentrate his full attention on the job. The body measurements should not only be those which can be taken on a human being at rest or from the jointed models sometimes used by designers, but must take account of body movements.

A considerable number of studies have been made to determine the optimum measurements of work spaces, the forces which can be exerted by limbs in different positions and the ranges of adjustment necessary so as to cater not only for the averages but also for the ranges of body dimensions found in various populations.

Other studies have been made to determine the optimum sizes of handwheels, cranks and other manual controls requiring considerable force. Ease of operating these types of control appears to depend on the relationships between the extent and force of the muscular movements required and the speed at which graded, co-ordinated action can be carried out. Thus, although less force is required to turn a large diameter crank than a small one, the greater extent of movement needed to turn the large crank may result in a slower speed of rotation.

The co-ordination of movement seems to be of special importance in relation to 'handedness'. The dominant hand has been found to be superior as a controlling member only where 'timing' or the serial organization of muscular activity is required. With coarser control movements there seems to be little difference between the hands. Differences between the two feet in the accuracy of control also appear to be small.



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The position of the knob is very much easier to see in the lower illustration than in the upper. This is partly due to its better shape and partly to its colour contrasting with that of its background.

Perceptual factors

An important feature of design for ease of use is that the state of the controls should be readily seen. Some designs are obviously better than others in this respect. Thus an 'up-down' switch indicates more clearly than a 'push-pull' switch whether it is on, and among rotary switches a 'pointer' knob is better than a circular one; switches of the 'rocker-dolly' and double-acting push-button types, give *no* indication of whether or not they are on.

Similar considerations apply to the 'feel' of controls. The sensory receptors in the muscles, tendons and joints, which enable the appreciation of limb movements give only poor indications of the absolute positions of limbs. Because of this, controls of the joystick type are often difficult to use if the stick moves freely. *Change* of limb position is perceived better, but the best sensory indications come from the application of *force*.

Joystick and lever controls are thus easier to use when they require pressure, and when the degree of deflection from zero position is related to the pressure applied. There is, indeed, evidence that more rapid and accurate control is achieved where the stick or lever hardly moves at all and practically the whole controlling effect is produced by pressure. Part of this is doubtless due to the control being self-centering. How much pressure is desirable depends upon the balance between two conflicting factors. On the one hand, pressure which requires muscular tension, and cannot be exerted simply by the weight of a limb resting on a lever or pedal, will tend to be fatiguing. On the other hand, very light pressures may not be sufficient to produce a clear 'feel'.

Identifying different controls

A number of studies have aimed at specifying designs to facilitate the rapid selection of the correct one from among a number of controls.

For knobs which have to be selected by 'feel', experiments have shown that differences of shape are more readily distinguished than differences of size; they have also suggested sets of shapes that are unlikely to be confused with one another.

More important as regards automation equipment are the problems arising when several controls have to be used in sequence. As in the perception of displays, the operator's task is greatly eased if he can apply a uniform rule of procedure by which to select the right control at each point in the sequence instead of having to 'think' about each controlling action separately. The best rule is not always intuitively obvious, and depends upon how much the sequence of actions varies on different occasions. Where controls are always used in the same order it is easier to have them arranged so that the operator has to work first one and then the next along a row. Where the order is not always the same the operator will need to rely to a greater extent on his 'mental picture' of the process he is controlling and of the ways it is affected by control actions. In this case it may be better to arrange the controls in such a way as to emphasize their function, and indicate the way their functions are related to one another.

The kind of rule required will also depend upon how the operator conceives the task. To take a simple example, when starting up a plant he may have to switch on some circuits and switch off others used during 'standing' conditions. The question is, should all the switches move in the same direction to start the plant so that he can follow a single rule of action to start up and shut down? Alternatively, should all the switches move down for 'on' and up for 'off' (or vice versa) so that they consistently indicate the state of the circuits concerned? If the operator needs to conceive the process in detail, the first type of rule may conflict with his 'mental picture' and the second type would be preferred. The first type, however, is less likely to lead to confusion and mistakes should an emergency shut-down be required.

Research on the design of controls has in the past brought a number of surprises, and the principles to be followed are not yet fully understood. This does not mean that nothing can be done immediately to improve designs, but that careful thought needs to be given to individual cases and should be supplemented wherever possible with experiments on prototypes or 'mock-ups'.

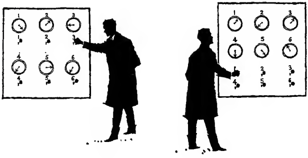
5. RELATIONSHIPS BETWEEN DISPLAY AND CONTROL

It has become clear in the course of research on displays and controls that many of the most important problems in their design cannot be solved in terms of either one or the other alone but concern the relationships between them.

There are really two distinct problems which are grouped together under this head. The first is how to design the layout of control panels in such a way that instruments and their corresponding controls can be readily associated. The second is a group of questions concerned with the relations between controls and their effects.

Associating display and control

It is perhaps obvious that simple matters of spatial arrangement can affect the ease with which a control panel can be used. For example, operators will tend to be slower and less accurate when they have to look away from the display in order to see the controls than when both are close together and can be taken in at a single glance.

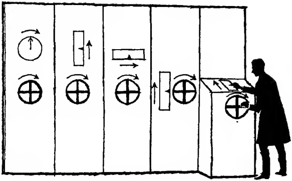


(*a*) (*b*)

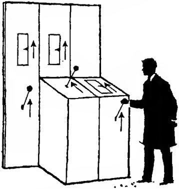
(*a*) Each control knob is placed immediately below its corresponding display. This is the most straightforward way of associating display with control.

(*b*) All the displays are at the top of the panel and all the controls at the bottom in the same relative positions. This arrangement enables the operator to adjust controls without obscuring any of the displays with his arm.

More important are cases where several displays, such as instrument dials, each have an associated control. Usually each display should be placed immediately above, or to the left of, its associated control. If this is impossible, some simple rule relating the one to the other should be apparent. A suitable arrangement from this point of view is to place each control in the same position relative to other controls as its display occupies relative to other displays.



Hand wheels, cranks or knobs



Lever controls

Relationships between Displays and Controls

The associations between the directions of movements of pointers on scales and of controls which produce these movements are shown by arrows.

Controls and their effects

The operation of an industrial machine tool, just as the driving of a car or the flying of an aircraft, involves a constant interplay between perception and action. Action taken in relation to signals from the display does itself in turn affect the display. The precise ways in which the results of control action are observed can profoundly affect performance.

Time lags between controls and their effects. Appreciable time lags between the operation of a control and the appearance of its effects on a display can in some cases lead to violent over-controlling and 'oscillation'. The difficulty lies in the fact that the operator cannot immediately observe the results of his actions. He can overcome the difficulty by anticipating these results and adjusting his action accordingly, but to do so he will have the very difficult task of learning just how much movement is required to produce any given result.

The operator's task is made more difficult still if the relationship between his controlling actions and their effects is not entirely straightforward. An example is where the movement of a control affects the *rate of change* of a process so that any control action requires two adjustments, one to start the change and another to stop it when it has gone far enough.

In these cases the task can be substantially eased if the necessary 'computations' are 'built into the machine' and the time lag eliminated by giving the operator a display which incorporates these computations and thus shows immediately what the eventual effect of his actions will be.

Some relationships seem more 'natural' than others. Most people when they first operate a new machine, expect that there will be certain relationships between display and control. If they are wrong they are able to learn different relationships, but the need to unlearn their original expectations and substitute other 'rules' may lengthen the time required for training. Common observation suggests that relationships which run counter to normal expectations can, even when they have been familiar for many years, lead to occasional errors when arbitrary rules are momentarily forgotten and normal expectations assert themselves again.

Some of these expectations appear to be wholly the result of popular conventions: examples are the clockwise turning of a tap for 'off' and (in Britain) the pressing of electric switches down for 'on'. The expectations that for 'increase' an electrical control knob should be turned clockwise and a lever moved to the right are probably of the same origin.

Other expectations seem to be in terms of a simple linkage between perception and action, similar to that of the ordinary co-ordination between hand and eye, or of a simple 'mechanism' connecting display and control. Thus where the pointer on a linear display scale is controlled by a knob, the tendency is to assume that the pointer moves in the same direction as the part of the knob nearest the scale, as if the two were geared together by a rack and pinion.

These expectations are not always consistent with one another. A conflict occurs, for example, with pointers moving on circular scales. If the clockwise movement of a controlling knob situated below the dial moves the pointer clockwise, the top of the knob and the pointer will both move in the same direction while the pointer is near the top of the scale, but will move in opposite directions when the pointer is at the bottom. When the pointer normally works over a particular part of the scale this difficulty can sometimes be overcome by moving the zero-point on the dial so that the pointer normally appears near the top.

Conflicts of this type clearly involve balancing one possible source of confusion against another and therefore demand careful consideration of individual cases; it is not sufficient to assume that the different confusing features are likely to have equal effects and that there is therefore nothing to choose between the various arrangements.

4. THE NEED FOR STANDARDIZATION

Over the whole field of the design of displays, controls and the relationships between them there stands the need for *consistency*. This consistency is required both between the different displays and controls of any one machine and also between one machine and another, so that the number of 'codes' or 'rules' that an operator has to remember is kept to a minimum and the possibility of conflict between one 'code' or 'rule' and another is avoided. Inconsistency may not lead to markedly poor performance, but will mean that there is more for the operator to bear in mind while carrying out his work. There will thus be greater likelihood of strain, confusion, errors and accidents, especially at times of stress.

The arrangements which are easy and 'natural' should be ascertained where they are not already known and then rigid standardization should be insisted upon. Where expectations conflict or do not clearly exist, standardization should still take place so that conventions can be built up to assist operators to transfer easily from one machine to another.

The rapid increase of new equipment at the present time offers a unique opportunity for such standardization which it is in everyone's interest to seize.

Suggestions for further reading:

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Murrell, K. F. H. Data on human performance for engineering designers. *Engineering,* 1957, **184**, pp. 194–8, 247–9, 308–10, 344–7, 438–40. Reprinted as a booklet.

Woodson, W. E. *Human engineering guide for equipment designers.* University of California Press. 1954; London: Cambridge University Press.

Papers of interest in this field appear in a number of scientific journals, of which the following may be especially mentioned:

Journal of Applied Physiology
Journal of Applied Psychology
Ergonomics
Journal of Experimental Psychology
Human Factors
Occupational Psychology

III. HUMAN CAPACITY FOR MONITORING AND CONTROL OPERATIONS

Some of the most fundamental considerations which bear upon the design of automatic equipment emerge more clearly when the problem is turned around, so to speak, and looked at in terms of human capacities and their bearing upon work design, rather than in terms of detailed points in the construction of equipment.

1. MAN AS A 'COMMUNICATION CHANNEL' OF LIMITED CAPACITY

Man receives data from his surroundings through many sensory channels and combines them with past experience to produce action. The process of doing so implies decisions about what has occurred and what actions are required in response—in other words, discrimination of one signal or event from another and choice between possible alternative actions.

Only a certain amount of such decision-making can be done in any given length of time, and the time required to make decisions rises as discrimination becomes finer and choice more complex. If the required time is not spent, accuracy suffers. Indeed, errors may be thought of as resulting from the exercise of insufficient discrimination or choice.

'Mental' work can thus be treated in quantitative terms, and any given task can be conceived as imposing a 'mental load' upon the operator in terms of the rate at which he is required to transmit information from display to control. It is to be emphasized that the load is '*mental*'. The speed at which a task is carried out is mainly determined by the speed at which certain brain mechanisms function and is not normally limited by the action of sense organs or of hands and feet.

Although this load results mainly from the transmission of information from display to control, it may also arise from other sources, such as the sights, sounds and discomforts of the environment—hard seats, talking by companions, noises of other machines and so on. Again, any irregularities or uncertainties introduced by non-uniform materials or unreliability of machinery will increase the load and thus the time taken to do a job, or the likelihood of making errors.

So long as the operator is free to do his work at his own pace he will adjust his rate of work so that the load upon him never exceeds his capacity. In practically all automatic work, however, the pace is set not by the operator, but by the machinery he is using. Clearly there is in these cases the possibility that the pace, and therefore the load, will be too great. Even when the average load is well within the operator's capacity occasional overloads may occur if 'bunches' of signals arrive together and have to be responded to within rigid time limits. Overloads may also result from trying to give attention to interruptions or to distracting events going on around.

When overloading occurs it is inevitable that some of what should be done is omitted or that errors are made so that performance temporarily breaks down. Although this may happen only very rarely it must be reckoned as a potential cause of accidents. It is thus important, in the interests both of efficiency and of safety, that machinery and plant should be so designed that overloading is impossible. This can be done partly by taking steps to limit the number of things that can require attention at any one time, and still more by ensuring that time limits within which action has to be taken are such that, however many signals for action occur together, all can be dealt with before it is too late.

The likelihood of overloading the operator is much greater in operations where a process is remotely, but not automatically, controlled, than when full automatic control has been installed.

2. STORAGE OF DATA IN SHORT-TERM MEMORY

All human skills are obviously dependent on the very great amount of experience that is stored in memory; indeed the range and detail of this memory is one of the most important human characteristics. It is less commonly recognized that performance depends at least as much upon short-term retention from moment to moment which enables data arriving at slightly different times to be integrated and often makes it possible to smooth out temporary overloads by holding an excess of incoming information until it can be dealt with. The amount that is retained briefly in this way and then forgotten completely must in a lifetime be very large indeed—many times greater than the amount that is stored in longer-term memory.

The capacity for short-term retention at any one point of time is, however, surprisingly limited. Also, the material stored in short-term memory seems to be liable to disruption or interference by other activities during the period of retention. Most people know the experience of having a point they intended to remember 'driven out of mind' when their attention has been momentarily diverted elsewhere.

The limitations of short-term retention and the ways in which they can be mitigated or overcome are still far from completely understood. It is, however, a very important aspect of performance and one which is liable to cause difficulty, especially to older people and to operators who are fatigued.

High demands for short-term retention are liable to cause strain and anxiety. Examples of jobs where this occurs are those where the operator has to note trends and slow changes of readings on meters, or where he has to adjust controls and then leave them until a critical point some time later when he must remember to adjust them back. Retention can often be transferred from the operator to the machine he uses, for example, by using graphic recorders instead of meters. Doing so would seem very often to be an important and extremely worth-while means of making a task easier and of reducing the risk of accidents.

5. FATIGUE AND BOREDOM

A classical study of industrial work noted that the pace of a job, when not under the operator's control, could profoundly affect both his achievement and his subjective feelings.[1] Four 'zones' of speed can, perhaps, be distinguished.

(i) If the rate is very fast the operator shows signs of strain and fatigue. In his hurry he may make errors, or omit items, and as a result achieve less than he would with his machine running more slowly.

(ii) With a somewhat slower rate these signs of strain disappear, the operator's interest is fully engaged and he does his work well.

(iii) Rates a little below this optimum lead to feelings of boredom and unwillingness to do the task. Again the operator may omit items or make errors, due in this case to momentary lapses of attention.

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[1] WYATT, S., and FRASER, J. A. The Effects of Monotony in Work. *IHRB Report* No. 56. London: H.M.S.O. 1929.

(iv) A still slower rate again produces tolerable conditions and adequate performance. Most of the operator's time is spent doing something other than his main task—such as reading a book or talking to his neighbours.

For the operator of automatic equipment fatigue and strain would be very unlikely to result from an excessive demand for *physical* activity, but might arise from his having to make too many rapid decisions—or in other words from the need to transmit too much 'information' from display to control.

Although boredom occurs in situations where the operator has too little to do or observe, this is neither a matter of sheer physical inactivity, nor is it due to lack of sensory stimulation; a person can be bored although he is both physically active and surrounded by stimulating sights and sounds. Boredom seems rather to result when a task is repetitive or uneventful so that future events are monotonously certain. In other words, boredom occurs when the amount of information the operator has to transmit is small. A human being needs, perhaps, to transmit a certain amount in a given length of time to maintain interest in what he is doing, and will actively seek to keep up to an optimum level. Thus, if the main task on which he is engaged does not provide enough information to prevent him from becoming bored, he will engage in conversation or other activity to make up the required amount. The most boring jobs appear to be those in which the operator is less than optimally loaded but cannot make up the deficiency in these other ways.

Differences appear to exist between individuals in what rate of working produces what effects: in particular, the optimum rate for an individual falls with diminishing intelligence. The best way of dealing with a boring job might, therefore, appear to be to employ people of less than average intellectual capacity. This would often mean, however, that the operators could not be relied upon to take appropriate action in unusual circumstances or emergencies. If, therefore, optimum conditions are to be maintained, one of three courses seems to be indicated:

(i) Some strictly unnecessary work may be added to the task. In some plants operators have periodically to record readings from instruments they are watching, although the data are of no use except as a check that the instruments are being inspected.

(ii) It may be possible to design operations in such a way that they require approximately the same level of intellectual activity under all the different conditions that may occur.

(iii) Two people may be employed—one to do the simpler task of watching and one to be called in if action requiring greater intelligence, skill or initiative is likely to be needed.

'Vigilance' tasks

A parallel has been drawn between the job of a process control operator and the performance of subjects in a number of experiments undertaken during and after the second world war to study the changes of 'vigilance' during watchkeeping, especially among radar operators. The experiments showed that performance fell somewhat during the first 20–30 minutes, but thereafter remained fairly steady; it seemed as if the subjects performed initially at a level above that which they could maintain over a long period. The tasks were unusual in that they required the detection of infrequent, faint signals of brief duration which were barely discriminable against their background and occurred at random intervals of time. The criterion of adequate performance was whether these signals were observed.

Under these conditions the subject must make a continuous series of very rapid decisions as to whether a signal is present, and cannot afford to 'let up' for a moment without running the risk of missing one. The fact that the signals are infrequent means, however, that the total information conveyed is small. The task is thus one which is likely to be both fatiguing and boring.

Conditions are less rigorous when there are clear signals which do not come and go but remain on the display until dealt with. In these cases the operator's performance does not fall appreciably over considerable periods of watching, although the time he takes to deal with signals may sometimes lengthen a little. Monitoring tasks in automatic plants appear to fall almost entirely into this latter category and are thus unlikely to demand unduly high levels of vigilance. It is, however, worth noting the conditions under which this holds true and trying consciously to ensure that it remains so when designing new plant.

4. EFFECTS OF EXPERIENCE

When the effects of continued work are considered on a very much longer time scale it is found that extended practice on a job substantially improves performance in many ways. This is so not only during any period of formal training but often for many years after: the rate of improvement slows, of course, but significant gains continue.

Four effects can be distinguished:

(i) The operator learns facts about his task and about the layout of the equipment. These enable him, for example, to 'read' dials accurately at a distance too great for him to be able to see the individual figures. The factual knowledge also provides him with a 'mental picture', though often a rather crude one, in which the various parts of the task and of the equipment can be related.

(ii) Sequences of events which regularly occur together are recognized, so that, once the first member of the sequence has arrived, the rest can be inferred without each having to be observed individually. This kind of grouping seems also to occur with sequences of actions, which become welded into rhythms or 'habits'.

(iii) Even though strictly regular sequences of events do not occur, the operator may learn the relative probabilities of different events and thus be better prepared to deal with common occurrences quickly. This he does, of course, at some expense of speed in dealing with rare events.

(iv) In the course of long experience, most of the rare events which can happen do occur, so that they become known and the techniques of dealing with them are tried under real conditions instead of as training drills.

As a result of these various types of learning the operator gradually eliminates inefficient methods of work and 'takes the measure of the job'. The first two effects in particular render him less dependent upon immediate information about the details of his job, and reduce his 'mental load' because individual signals and actions no longer require separate decisions. These larger 'units' of perception and action may be attained at the cost of some flexibility, so that a man who is well used to one set of unvarying conditions may be less able to transfer to conditions which are different. There is some evidence that his main difficulty is in transfer to conditions only slightly different: where the difference is large, little trouble is likely to arise.

Experience may in many cases rid the operator of a very real fear of the unknown which cramps his early efforts. There are, however, a few jobs where experience appears to lead to the opposite effect. These all have the characteristic that there is some unpredictable hazard always present or some frightening events which have inevitably to be faced. The threat of a danger which no amount of care can entirely remove seems gradually to lead to anxiety and an unwillingness to continue in the job. In these cases, increased experience merely serves to emphasize the reality of the hazard. The *malaise* shown in these circumstances is, perhaps, similar to that shown by a man who cannot relinquish a job which is too difficult for him—indeed the job with an unpredictable hazard, is in a very real sense, difficult to the point of impossibility. The general point to be noted in both cases is that conditions which are tolerable in the short term, or when an end to them can be seen, may not be tolerable when continued indefinitely.

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IV. MAINTENANCE WORK

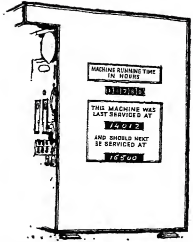
Discussions of automation commonly use the term 'maintenance' to cover both preventive maintenance and repair. The second type of work usually makes much greater human demands than the first and the two ought to be distinguished.

Preventive maintenance can be made a matter of rule-of-thumb routine procedures. Repair work, however, especially upon electronic apparatus, often demands intellectual ability well above the average of the normal population. It would seem worth while to take very considerable trouble, on personnel grounds alone, to ensure that the need for repairs is reduced to a minimum and that failures of equipment are either prevented or anticipated.

1. PREVENTIVE MAINTENANCE

Much of this is a matter of oiling and cleaning which, it is often recommended, should be done by machine operators rather than by a special maintenance staff. Some means of easing such work are obvious, such as designing for easy accessibility and the formulation of routine procedures that are readily understood. Perhaps less obvious is the need for showing when attention is due: if maintenance is not carried out daily or at regular longer periods but is in terms of amount of use, an indicator should be fitted on the machine showing how much it has been used and when the next maintenance service is due. Evidence should also be available to the machine operator and his foreman that maintenance has been carried out at the appropriate time and has been effective.

Many tests of electronic apparatus can be reduced to a routine, especially if check points are brought out to positions where they can be easily reached. Clearly, the grade of man required to do this work will depend upon the complexity of the test apparatus he has to use, and it is desirable to make this apparatus simple wherever possible. For example, if it is necessary to give routine tests to a series of voltages, the test points on the apparatus can be arranged so that all can be examined with a single-range meter.


MACHINE RUNNING TIME IN HOURS
14760
THIS MACHINE WAS LAST SERVICED AT
14012
AND SHOULD NEXT BE SERVICED AT
16500

This information should be recorded not only in the maintenance engineer's log book but also on the machine so that is it available to the operator.

Studies of the 'lives' of some components have made it possible to predict accurately the time for which they will operate with any given probability of breakdown, and thus to replace them as a matter of routine a certain time after installation. Such studies can obviously save a substantial amount of skilled repair work.

2. REPAIR WORK

Methods of organizing mechanical repair work have had a long development, and the need for such features of design as simple construction, rigidly standardized parts and easy accessibility is well known. Ways of easing the task of electronic repair work are less well understood and have been the object of a number of researches in recent years. These researches have been done almost entirely in relation to equipment for the armed services, but many of them have implications for industry.

The execution of repair work is obviously made easier by the use of 'plug-in' units which can be substituted quickly and which enable faulty units to be taken to a workshop for treatment instead of having to be repaired on the factory floor. However, the execution of repairs is commonly less difficult than the diagnosis of faults. Difficulty arises because there are often several possible causes of breakdown which produce very similar effects and, to find which component is at fault, the repairer has to proceed either by a very tedious process of 'trial and error' or by piecing together data and making logical inferences. The latter procedure is usually preferable. Two main methods of facilitating it have been put forward.

Means of gaining a rapid understanding of the apparatus

The circuit of an elaborate apparatus can be conceived as a collection of smaller sub-circuits, each of which follows more or less conventional lines and is common to several different types of equipment. An electronic engineer will, in the course of training and experience, come to know these, so that it would seem helpful to give him diagrams in which they can be recognized quickly.

It is seldom easy to sort out the components of the various sub-circuits from an ordinary theoretical circuit-diagram. The common practice of supplying a block-diagram in which the various sub-units of the whole circuit are set out is often of substantial help, but attention needs to be given to the detailed circuit diagram itself. This should ideally be drawn so as to separate the various sub-circuits and emphasize their functional relationships. The sub-circuits could well be placed in the same positions as they occupy in the block diagram so that both diagrams correspond. Different spatial arrangements are almost inevitable, however, between the circuit diagram and the actual apparatus. To facilitate tying the two together it is valuable to provide, as is commonly done, a third diagram showing the actual layout of the main components denoted by symbols or descriptions corresponding to ones on the circuit diagram.

Procedures for systematically diagnosing faults

The writer of a well-known book on radio-servicing confesses that during the lunch-hour he and his fellow students used sometimes deliberately to introduce faults into their chief's apparatus.

The methodical way in which the chief went about tracing these faults was a lesson, however, which stood them in good stead in their own work in later years.

A research study made upon a number of expert technicians revealed that practically all their initial procedures for tracing a fault could be placed in four classes.

(i) An approach to the 'split-half technique', in which, ideally, the technician first eliminates one half of the apparatus, then half of what remains and so on until the fault is located.

(ii) Systematic working *through*, either from input to output or vice versa.

(iii) Systematic working *outwards*, from some central point in the chain from input to output.

(iv) A 'probability approach', in which the technician tries first the components which previous experience tells him are most likely to be at fault.

Of these four types the first is logically the most efficient, and in the study proved the quickest, although all were equally successful in the end. The 'probability approach' was the slowest, doubtless because it often had to be followed by one of the others. All these systems were obviously superior to unsystematic 'trial-and-error' methods. One of the main difficulties of an unsystematic approach is that the subject cannot remember what components he has tried and so repeats some of the tests he has already made, while overlooking the test which can tell him what he needs to know.

It must be emphasized, however, that these studies were made on problems which were relatively simple compared with some of those encountered on large electronic computers. With very complex apparatus in which there are many interacting connections, the task of making a strictly systematic diagnosis may be of such a magnitude that a probability approach is worth using initially, especially if the probabilities of different faults are known.

Other studies have indicated that diagnosis is often quicker and more systematic if the technician consciously thinks out his procedure, and the possible faults to look for, before he starts than if he immediately begins making tests.

The study of methods of testing electronic equipment and diagnosing faults has not yet developed very far, and further work would probably be well repaid. It should cover not only systematic procedures of fault-finding but also the design of test apparatus for easy use and of equipment for easy comprehension and repair.

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will tend to become chronically frightening for a man who possesses both imagination and conscience.

Ensuring responsible operators is probably, in the present state of knowledge, a matter more of selection than of training. Willingness to undertake responsibility seems to depend upon personal qualities which are not found among all members of the population. They may thus attract reward on grounds of rarity if for no other reason. The attitude of the responsible operator of automatic equipment seems to be characteristic of a 'vocational' or 'professional' approach to work, and several writers have suggested that his job will tend eventually to become a salaried post.

2. ISOLATION

It is sometimes suggested that an unsatisfactory feature of some jobs in automatic factories is that people on them have to work in isolation from their fellows. This danger is probably exaggerated since many of those who appear isolated are in frequent touch by telephone with colleagues and supervisors. The telephone is probably, however, not a complete substitute for direct human contact. Where the operator is less than optimally loaded the inability to talk to other people may result in boredom. Also responsibility may weigh more heavily on a man who works alone since he must take many decisions unaided which would be checked or shared if others were working with him.

It is difficult to decide whether the kind of isolation likely to be met in 'automation' work has other human implications than these. Half a century ago one would have said that an 'instinct of gregariousness' would be frustrated. Although the term is not now used in psychological discussions, common observation leaves no doubt that some people have a greater need for companionship than others. Why they have is a question at present impossible to answer.

The problem of isolation differs a little according to whether the operators are out of sight of one another or whether they can see their neighbours but cannot, because of distance or noise, converse with them. From the operator's point of view the latter condition may be just as conducive to boredom as the former. From the management standpoint the former condition has the difficulty that failures due to sudden illness might go undetected whereas under the latter they would be quickly seen by neighbours. This point might also substantially affect the confidence of some operators.

If isolation is inevitable, its effects can be mitigated by periodic visits of supervisors and others. How often these should be made and how far they can act as a substitute for the continual presence of others is a matter which would perhaps repay study.

5. SHIFT WORK

Several writers on automation have mentioned a tendency towards more shift work in order to make heavy capital expenditure on new machinery economically justifiable.

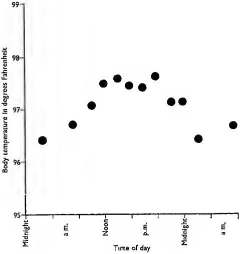
There is no doubt that shift work imposes strains upon the people concerned. It is the subject of many complaints and these tend to rise among older people and others who are in some way less robust than normal. On the other hand, a few seem to enjoy night work and prefer it to working at the usual hours. What circumstances or traits of personality make them do so are not known. Clearly, however, there are not enough of them to provide for the amount of shift work needed, or likely to be needed, in the future.

The problems of shift working differ somewhat with differing systems of hours—for example, two day-shifts cause less problems than a three-shift system which includes night working. In all cases, however, especially with night working, there are two main types of problem, one physiological and one social.

Physiological issues

It is known that body temperatures and physiological functions vary during the cycle of 24 hours. If the times at which an individual gets up, has meals and goes to bed are shifted, for example, by changing to night work or travelling by air to a different longitude, the bodily rhythm gradually adjusts until it is in step with the new times. However, the adjustment takes several days or even weeks and, until it has been completed, the individual works at somewhat less than full efficiency and may possibly be more than normally liable to minor ailments.

Each change from day to night work, or vice versa, will be followed by a few days of disturbance in the bodily rhythms, and during these periods complaints are made of tiredness due to loss of sleep and of indigestion or lack of appetite due to taking meals at 'unsuitable' times.



Body temperature readings taken at intervals throughout the 24 hours. Readings were taken every two hours except between 2 and 8 a.m. The points shown are the averages for a group of 12 people. The graph is based on data in a paper by P. R. Lewis and Mary C. Lobban. (*Quarterly Journal of Experimental Physiology*, Volume 62, 1957)

When the changes of shift occur at weekly or fortnightly intervals the body may never have a chance to settle down fully. From the physiological point of view, therefore, permanent work on a given shift is to be preferred to alternating periods of day and night shift, though permanent night shift work should imply keeping the same hours on days off as on working days.

This kind of schedule is not likely to commend itself widely. It would, therefore, seem desirable to study ways in which the transition from one shift to another might be made easier. Are there, for example, individual differences in adaptability? What kinds of food are palatable and at what hours are they best digested during the changeover period? In conditions of frequent change is *adaptation to changeability* acquired and, if so, what is the optimum schedule for producing it?

Social issues

Permanent shifts at unusual hours cause obvious difficulties in family and social life. It may be difficult to fit in with hours dictated for the rest of the family by children at school, and problems may arise because hours available for shopping or entertainment may not match well with those of work. It is doubtless these difficulties which lead many shift workers to prefer a change-round of shifts once a week to permanent work on night shift, in spite of its physiological disadvantages.

These social difficulties could obviously be very greatly eased if hours of shopping, entertainment and catering were longer, and if hot meals of both 'breakfast' and 'dinner' types were available at most times of day. Changes of this kind would, of course, have repercussions far beyond the actual factories or offices concerned and would imply a substantial departure from the present patterns in this country. They would require a sympathetic understanding of the problems of shift workers by all concerned and probably some encouragement from legislation.

4. TRAINING

Although operators require little training for many of the new types of work created or expanded by automation, special methods may be needed in some cases. An example is electronic maintenance, which is recognized as difficult but for which no well-established tradition has yet been built up. More important during changeover periods are likely to be the problems of re-training operators in middle age—a time of life at which it is commonly believed to be difficult to acquire new skills.

It is, of course, clear that men have been successfully trained or re-trained in the past, but whether their training was as efficient as it might have been is not known. What evidence there is from the study of industrial training suggests that it could probably have been improved, although whether the gain would have been worth the trouble of special methods is often doubtful. A full discussion of industrial training in relation to automation will not be attempted here, but a few outstanding points will be briefly mentioned.

Almost all the systematic studies that have been made of industrial training—and they are very few—have concerned fast, manual, semi-skilled work. Apart from these studies, guidance comes mainly from experimental researches on learning, using artificial laboratory tasks. The relevance of these to industrial conditions is not always clear, but some results are suggestive and have echoes in industrial experience.

The experiments suggest that four points should be borne constantly in mind when designing training methods:

1. *A prior condition of any successful training is that the material to be learnt should be fully and correctly comprehended by the trainees.* This means that attention must be given to the manner of presentation and the pace of instruction, with concentration upon points of difficulty.

2. *The trainee must be able to observe the results of his actions,* so that he can modify his performance in the light of any errors made. To be maximally effective this 'knowledge of results' needs to be available as quickly and directly as possible.

3. *Only a limited amount can be learnt on any one occasion.* Training sessions should be relatively short and interspersed with other activity. Training has in some cases been found easier if operatives can initially spend short periods on new work, returning to their old jobs in between. Jobs can often, with advantage, be split up into components, each of which is learnt separately before it is combined with the others.

4. *Initial reactions to a new task tend to persist.* It is a well-known principle that in the teaching of games, or skills such as typewriting, errors should be corrected at once as they tend quickly to become ingrained. Similarly, the method first adopted for tackling a problem or doing a task tends to be carried over to later occasions. It is of especial importance to try to secure that initial performances by trainees are accurate and that they do not acquire erroneous habits which will have to be unlearnt later.

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The main problem of training men and women in later life appears to stem first from difficulty of comprehension and, secondly, from a reduction of the amount that can be learnt at one time. Normal older people seem to be able to learn small amounts as rapidly and completely as younger people. Thus their difficulty appears to be not in 'registering', but rather in the actual process of taking instruction. The various points already mentioned as likely to aid training would seem to apply to older people with special force.

Older people often appear to find particular difficulty in framing what they have learnt in words, even though able to show it in other ways. Also, their difficulty in comprehension is a matter more of speed than of level of complexity so that giving them control of the pace of instruction is likely to be of particular assistance.

Two further points should be mentioned. The first is that older people appear sometimes to get on better with instructors who are their contemporaries or seniors, than with those who are younger. Why this should be so is not clear: it may be due in part to resentment at being taught by someone younger than themselves or it may be that a younger man tends to teach too fast or with pre-suppositions and a background of experience different from those of older trainees.

Secondly, as age advances, so changes in various bodily mechanisms—of wind, limb and brain—result in alterations to the method and manner of performance: for example, actions may become slower but more careful and accurate. The methods adopted by older people tend in a remarkable way to make the best of the powers they have available, and can be said in a sense to optimize their performance. It follows that not only the pace but the actual content of training for older people may need to be different from that given to younger trainees if the results are to be fully successful.

5. JOB SATISFACTION

Satisfaction or dissatisfaction with work is in large part an end product of the various factors already discussed and should not be considered apart from them. However, a number of other factors of a rather different kind have been suggested as also being likely to affect job satisfaction. Some have to do with the temporary conditions of changeover to new methods of working, others with the characteristics of the new work itself. A full examination of these matters is beyond the scope of the present survey, but a few of them will be mentioned briefly.

Problems of changeover

Even if the change to automatic working produces no major upset such as large-scale temporary redundancy, it is bound to disturb the delicate structure of prestige and relationships between various people in an organization. Few people realize how nicely graded and how widespread these relationships can be, how they affect not only the men themselves but also their wives and families, how deep is the resentment that can be caused by their disruption and how long they may require to become re-established. The attitudes men take towards new methods will obviously vary according to the way these seem likely to affect them—those who recognize that they will benefit are likely to welcome the change; those who believe, rightly or wrongly, that they may suffer will complain. The complaint will often not be directed at the true cause but at some feature of the work or organization.

The benefits of change tend, on the whole, to be underestimated by those affected. Whatever benefits accrue there will almost inevitably be some particulars in which the old work is preferred. It appears to be a common human characteristic to pay most attention to what is difficult, inconvenient or unpleasant, and a man's whole attitude may be coloured by relatively minor details that strike him in these ways. There is, perhaps, sound biological reason for this in that an animal which did not pay attention to difficulties and dangers would be at a serious disadvantage in the 'struggle for existence'. It means, however, that a well-designed scheme may cause trouble on the personnel side due to neglect of relatively trivial matters.

An interesting method of securing better appreciation of changes has been studied with telephone apparatus.[1] A change is made to a new system, and then after a few weeks, when users have given it a thorough trial, a change is made back to the old. Most people recognize advantages in the new system after the change back that they did not see, or admitted only grudgingly, when it was first installed. Changes back of this kind are clearly impossible in most cases of automation, but the point is worth bearing in mind if only for judging reactions to change.

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[1] KARLIN, J. E. Consideration of the User in Telephone Research. *Ergonomics*, 1957, **1** (1), pp. 77–85.

Is some work inherently more satisfying than other?

It is now generally recognized that knowledge of achievement at a task not only improves accuracy but acts as a powerful incentive, making work more satisfying than it would otherwise be. For the full effect, the knowledge must be available at once and must give clear information about what has been achieved. Some industrial attempts to use knowledge of achievement as an incentive have probably failed through neglect of these requirements.

This kind of incentive appears often to be lacking in 'automation' work, but may be replaced by what seems to be an inherently satisfying effect of being in control of powerful machinery. Why this should give rise to satisfaction has never been studied but may possibly be due to a high ratio of 'effect' to 'effort'. Something of the same satisfaction may accompany the work of designing programmes for computers; a new programme, once made, is a unique and enduring product, capable of being used again and again and of directing a volume of work entirely out of proportion to the labour involved in working the programme out originally.

Looking at the broader scene in the country as a whole, some prophets have viewed with regret the possibility that automation will bring a reduction of skilled craftsmanship. It seems that this fear is exaggerated, if not actually wrong. It was said in the first chapter that the total number of people involved in the change to automatic methods is not likely to be very large. Also the construction of automatic machinery will probably maintain, and even increase, the demand for some types of trade and craft work, at least for many years to come.

Beyond this, it is, perhaps, not too fanciful to envisage that large-scale production by automatic methods of necessities and 'essential luxuries' may well free resources and increase opportunities for the craftsman and artist, and set a new value upon the uniqueness of their work.

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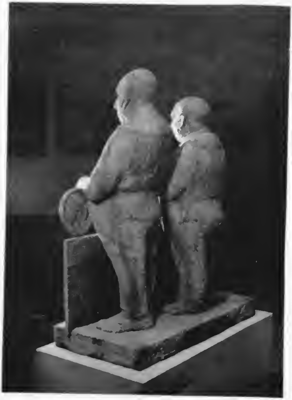
VI. CONCLUSION

The outstanding lesson that emerges from the studies done so far in the field that has come to be called *ergonomics*, is that the design of machine tools and other equipment according to sound engineering principles is not enough to ensure that their full potentialities will be realized. The machine and its operator inevitably form a single system in which the characteristics of both contribute significantly to the performance of the whole. Full account must therefore be taken of human abilities and limitations in the design of these systems if they are to operate to full advantage. The human characteristics concerned include not only the basic capacities of the human body and brain but also the effects of individual and social experience, the aims, ambitions, hopes and fears that a man brings to any task he performs.

While this is to some extent true of all industrial machinery, it is particularly important in relation to the design of automatic plant. Although automatic methods may reduce the immediate part played by human operators, they leave human beings in certain key positions in which the mental load upon them may be heavy and the effects of their actions far-reaching. The human link in the system thus becomes more and not less important than it was before.



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'The Machine Minders'

The sculptress, Miss Ghisha Koenig, is reported to have remarked that until she had entered a factory she had always imagined that machines were designed to suit the physical characteristics of the operators, but now she is surprised how frequently the man or woman has to arrange a box to stand on, or some other expedient to make the work comfortable! (*'Engineering'*)

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